Development of a Low-Cost Non-Dispersive Infrared Spectrometer for Real-Time Nitrous Oxide Detection

Zachary Holt[1], Dr. MD Shaad Mahmud[1], Dr. Wilfred Wollheim[2]

1) Department of Electrical and Computer Engineering, 2) Department of Natural Resources and the Environment, University of New Hampshire

Contact Information
Zachary.Holt@unh.edu

Introduction

Why N_2O?

- Nitrous oxide (N_2O) is the third-most problematic greenhouse gas, and is 265 times more potent than CO_2 [1]
- N_2O is the dominant ozone-deleting gas emitted by humans [2]
- Agricultural soils are responsible for 75% of U.S. N_2O emissions [1]
- Monitoring soil N_2O emissions is vital to understanding climate impacts as and promoting sustainable agriculture [4]
- N_2O emissions are highly variable, sometimes changing within hours and across single fields [3, 5]

Project Motivation

- Current N_2O sensing methods are costly and offer limited spacial and temporal resolution [3]
- A small, affordable, robust N_2O sensor can be deployed for real-time data collection to capture nuances in N_2O emissions

Technical Background

NDIR Theory

- N_2O absorbs IR light at 4.5µm
- When N_2O enters the chamber, the intensity of 4.5µm light decreases
- This change is proportional to the concentration of gas in the chamber, given by the Beer-Lambert Law

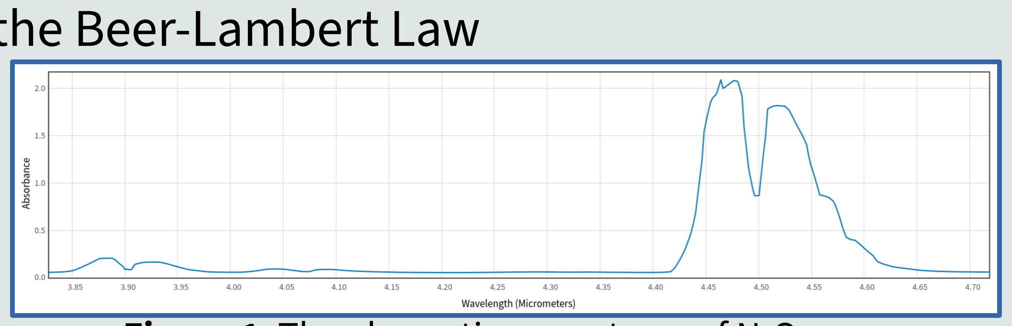

Figure 1: The absorption spectrum of N_2O gas.

The Beer-Lambert Law relates the absorption of light to the concentration of gas, given by:

$$A = \log(I_o / I) = \epsilon l c,$$

A = absorption
I = experimental light intensity, I_o = reference light intensity
ϵ = molar extinction coefficient
l = light path length
c = concentration of target gas

Adjustable Path Length

Since ϵ is constant, $A \sim lc$. When the path length increases, the absorption increases. For low concentrations of gas, increasing the path length improves the sensor's limit of detection.

Sensor Design

- Custom gas cell reduces costs
- Copper pipe used for high IR reflectivity
- Telescoping design allows for adjustable path length for varying N_2O concentrations
- O-ring seals ensure no sample gas escapes
- Modular design allows for easy maintenance and customization

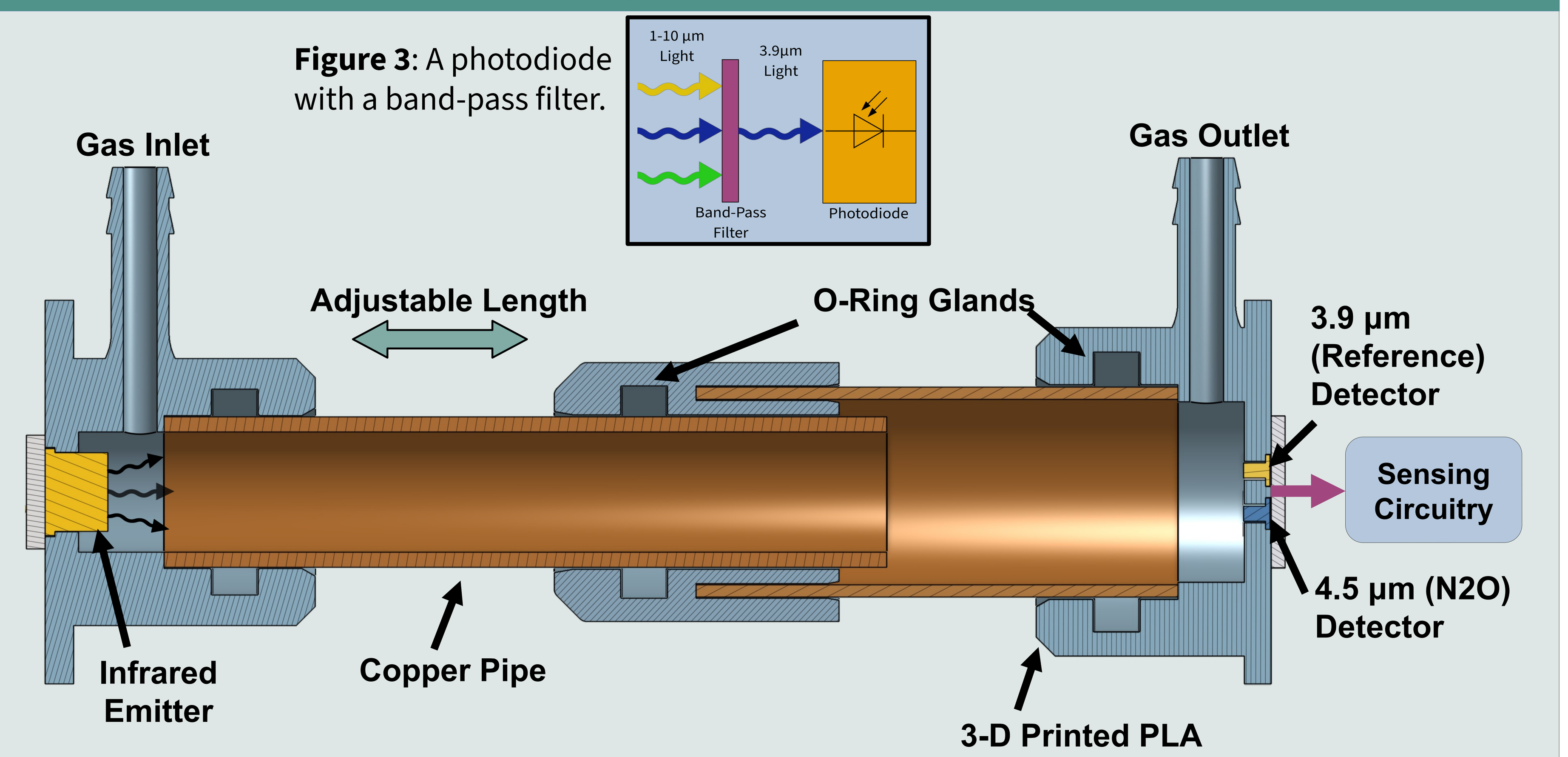

Figure 3: A photodiode with a band-pass filter.

Figure 2: A cross-sectional view of the sensor body CAD model.

Circuit Design

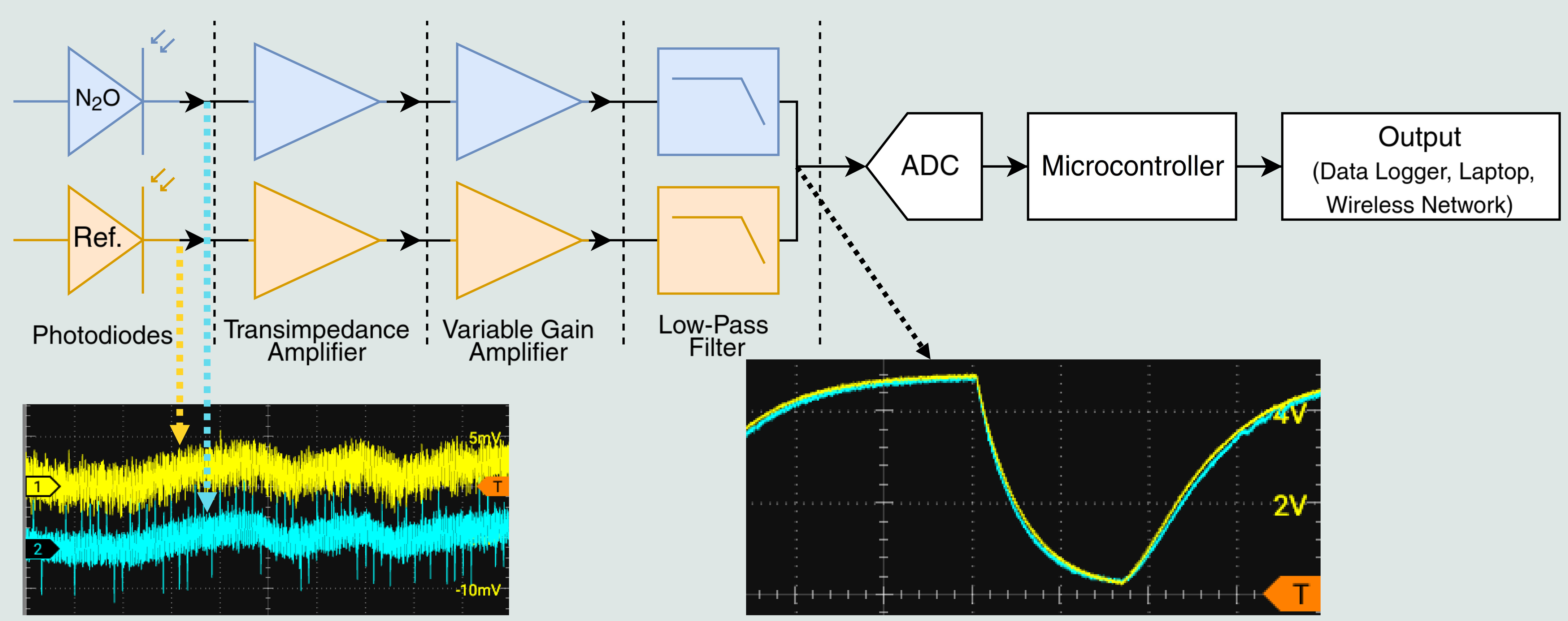

Figure 4: A block diagram representation of the sensor circuitry. A transimpedance amplifier is used to transform the photodiode current into a voltage, and the variable gain amplifier is used to adjust the signal amplitude for maximum ADC resolution.

Preliminary Results

Procedure

- Combined 1 kg healthy soil, 3 tbsp. 21-21-18 fertilizer, and water to saturate soil
- Soil mixture placed on 25°C (77°F) heater
- Gas captured from soil and directed into sensor
- Sensor outlet plugged, so gas accumulates in sensor

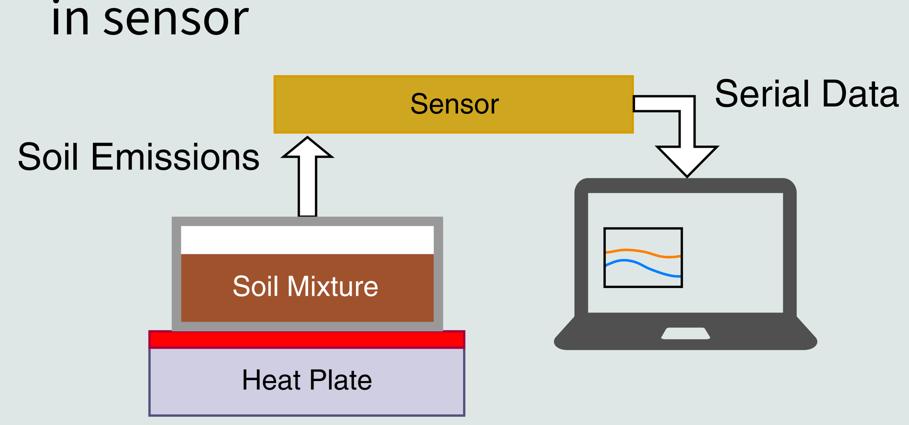

Figure 5: The experimental setup.

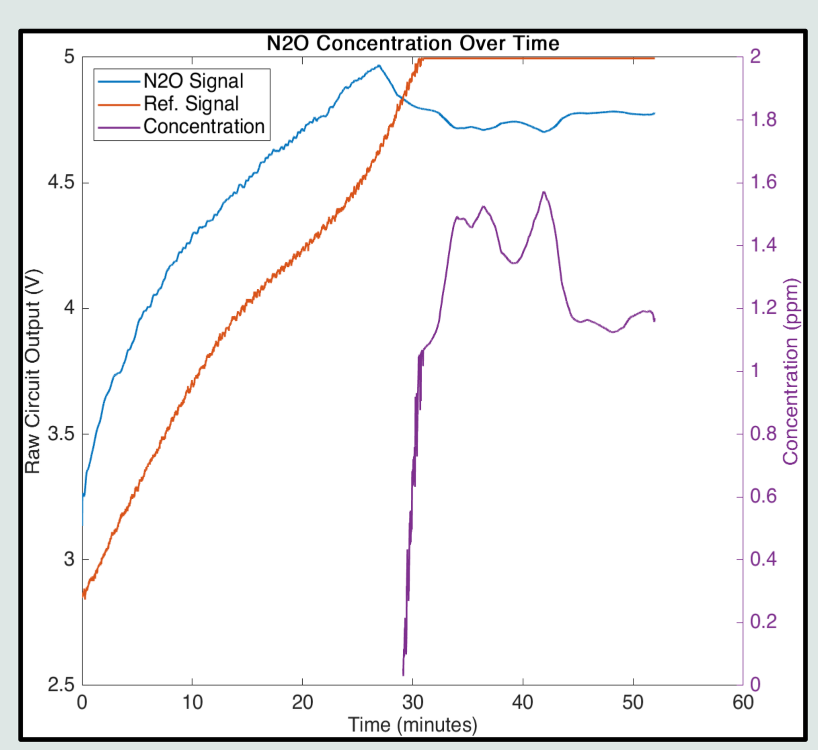

Figure 6: The results of the test.

Discussion

- Shows the process of N_2O detection with this sensor
- Concentration is a rough estimate
- N_2O signal was smoothed, as Arduino sampling introduced noise into the signal
- Generated N_2O soil emissions in a controlled environment
- Further work needed to validate these results

Cost Analysis

Sensor Cost Breakdown

Part	Cost
Photodiodes	$228.00
MIR Emitter	$57.79
Copper Pipe	$8.05
O-Rings	$0.30
Microcontroller	$19.50
Amplifiers and Filters	$27.20
Other Electronic Parts	$1.50
Total Cost	**$342.34**

Table 1: A breakdown of the sensor costs. Future costs can be reduced using surface mount components.

N_2O Sensor Cost Comparison

Technology	Cost
Quantum Cascade Lasers	$75,000
LI-COR LI-7820 [6]	$66,000
Gas Chromatography	$30,000
Unisense N2O Microsensor	$6,330
Bandara et al. – "Low-Cost NDIR"	$2,780
This Device	$342.34

Table 2: A cost comparison of other N_2O sensing technologies. While each technology has different applications, this design is extremely low cost compared to other designs.

Future Work

- Validate sensor with known N_2O concentrations
- Reduce sensor cost and bulk with SMD circuit parts
- Use LED emitter for increased life and power savings
- Integrate with soil N_2O sampling devices to measure soil N_2O flux
- Combine with a soil sampling device developed in the Real-Time Sensing Lab for total nitrogen measurement
- Add functionality for methane and carbon dioxide sensing

Conclusion

- High spatial and temporal resolution sensors are vital for understanding N_2O emissions
- This design allows for low-cost N_2O sensing that can be adjusted to a variety of applications, lowering the barrier to entry for N_2O monitoring

References

[1] US EPA, "Overview of Greenhouse Gases," Greenhouse Gas Emissions. Accessed: Dec. 28, 2024. [Online]. Available: https://www.epa.gov/ghgemissions/overview-greenhouse-gases

[2]A. R. Ravishankara, J. S. Daniel, and R. W. Portmann, "Nitrous Oxide (N2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century," Science, vol. 326, no. 5949, pp. 123–125, Oct. 2009, doi: 10.1126/science.1176985. .

[3] Z. Yao et al., "Comparison of manual and automated chambers for field measurements of N2O, CH4, CO2 fluxes from cultivated land," Atmospheric Environment, vol. 43, no. 11, pp. 1888–1896, Apr. 2009, doi: 10.1016/j.atmosenv.2008.12.031.

[4]S. M. Ogle, K. Butterbach-Bahl, L. Cardenas, U. Skiba, and C. Scheer, "From research to policy: optimizing the design of a national monitoring system to mitigate soil nitrous oxide emissions," Current Opinion in Environmental Sustainability, vol. 47, pp. 28–36, Dec. 2020, doi: 10.1016/j.cosust.2020.06.003.

[5] O. Mathieu, J. Lévêque, C. Hénault, M.-J. Milloux, F. Bizouard, and F. Andreux, "Emissions and spatial variability of N2O, N2 and nitrous oxide mole fraction at the field scale, revealed with 15N isotopic techniques," Soil Biology and Biochemistry, vol. 38, no. 5, pp. 941–951, May 2006, doi: 10.1016/j.soilbio.2005.08.010.

[6]"Mississippi State University Notice of Proposed Sole Source Purchase 234-64." Mississippi State University. Accessed: Apr. 20, 2025. [Online]. Available: https://srm.magic.ms.gov/SAP/EBP/DOCSERVER/LI-COR%20SOLE%20SOURCE%20NOTICE_UPDATED.DOCX?PHIOGET&KPID=45BCA8335E941EEEABFFDBA3D29F4A75&KPCLASS=BBP_P_DOC&SAP-CLIENT=100

[7]K. M. T. S. Bandara, K. Sakai, T. Nakandakari, and K. Yuge, "A Low-Cost NDIR-Based N2O Gas Detection Device for Agricultural Soils: Assembly, Calibration Model Validation, and Laboratory Testing," Sensors, vol. 21, no. 4, Art. no. 4, Jan. 2021, doi: 10.3390/s21041189.

Acknowledgments

Thank you to everyone in the Real-Time Sensing Lab and the CEPS Makerspace.

This project is funded by NHAES CREATE #11HN37.